arXiv:astro-ph/0405296v1 15 May 2004

PHYSICAL PROCESSES BEHIND THE ALIGNMENT EFFECT

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The radio/optical alignment effect for small powerful radio galaxies has been shown to be produced by shock waves formed by the interaction of the head of the jet and/or cocoon with clouds embedded in the interstellar/intergalactic medium. We present here preliminary results of analytical and numerical solutions that have been made to account for the production of implosive shock waves induced by embedding cold clouds in the radio lobe of expanding powerful radio sources.

1. Introduction

The radio/optical alignment effect in powerful radio galaxies was first observed by Chambers and collaborators[1,2] and has been extensively investigated by Best and collaborators[3,4,5,6]. All these observations show powerful radio galaxies that display enhanced optical/UV continuum emission and extended emission line regions, elongated and aligned with the radio jet axis. The expansion of the radio source strongly affects the gas clouds in the surrounding intergalactic/interstellar medium.

Best and his collaborators[7] showed that the emission from small radio sources ($\lesssim 150\,\mathrm{pc}$) were dominated by shocks most probably generated by the interaction between the bow shock of the jet and the surrounding medium. For large radio sources the emission appears to be the AGN itself.

From the various theoretical models that have been proposed to account for the emission observed, one of the most exotic ones was the idea that the interaction of the jet with clouds embedded in the interstellar medium induced the formation of stars. Based on the original idea of Begelman[8] we have constructed a model in which implosive shock waves were driven

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2

in the clouds after finding themselves immersed on very high pressure environments due to the passage of the jet.

2. Implosive shock–waves

When the head of an expanding extragalactic jet encounters clouds with much smaller radii than the radius of the jet, then one can think that the interaction hardly modifies the structure of the jet. The collision between the bow shock wave and/or the hot spot shock of the jet with clouds embedded in the interstellar and intergalactic medium is quite complicated. A very general 2D description of the collision between a plane parallel shock and a cloud was described in detail[9]. These calculations showed that after the passage of the shock wave, shocks and rarefaction waves are formed[10] which lead to the destruction of the cloud.

At first approximation one can model the interaction of a shock wave with a cloud as follows. The clouds are originally in pressure equilibrium with their surrounding interstellar or intergalactic medium. After being swallowed by the expanding jet, the clouds find themselves on an overpressured medium[8]. If the post-shock pressure is sufficiently large as compared to the pre-shocked pressure one can guarantee the formation of an initial discontinuity that produces an implosive shock wave and an expanding rarefaction wave, leaving a tangential discontinuity which can now be identified as the border of the cloud.

Well known similarity solutions for the problem of a non–relativistic explosive spherical shock waves have been found in the past[12]. A similarity solution for the problem of a relativistic shock wave was found by[14]. Both approaches, relativistic and non–relativistic are based on the idea that the energy content inside the shock wave is constant.

Guderley[11], Landau and Stanyukovich[12,13] found self–similar solutions for the case of a spherical shock wave converging to a centre, the so called implosive shock wave. For the case of a relativistic implosive shock wave we have found a similarity solution that generalises Landau & Staniukovich's model and takes into account some of the relativistic ingredients introduced by Blandford and McKee[14] for the relativistic explosive shock wave. The complete mathematical description of this model will be described elsewhere. Here, we briefly mention the most important results. For this particular case, the Lorentz factor Γ of the implosive shock wave is such that $\Gamma^2 = A(-t)^{-m}$, where the constant m represents the similarity index. Exactly as it happens for the non–relativistic implosive shock wave, due to

the fact that the energy is not conserved, one has to find the similarity index by demanding non–singularities on the equations of motion. By doing that and assuming a polytropic index $\kappa = 4/3$ we found that $m = 0.78460969$. With this similarity index it was then possible to find numerical solutions for the density, pressure and velocity profiles of the post–shocked material.

3. Astrophysical consequences

With the model presented in Section 2 it is now possible to apply the results to typical clouds in the interstellar medium. Inside the jet of a typical FR–II radio galaxy, the velocity of the plasma is close to the velocity of light, and the equation of state of the plasma is $p = e/3$, where e is the proper energy density. The pressure inside the jet has a typical value of 10^{-5}Pa. When this gas is shocked, the pressure grows to a very high value of 10^{-2}Pa. Under these circumstances, when a cold ($\sim 10\,\text{K}$) dense ($\sim 10^2\text{cm}^{-3}$) typical interstellar cloud with characteristic radius of $1\,\text{pc}$, finds itself inside the radio lobe of a radio galaxy, then an ultrarelativistic implosive shock wave is developed inside its structure.

The post–shock temperature, immediately after the shock reaches values of $10^{13}\,\text{K}$. The particle number density at this point is 10^4cm^{-3}. The cooling time τ_{cool} of the post-shocked gas was calculated[15] and its given by $\tau_{\text{cool}} = 3.72 \times 10^{14}$s. In comparison, the collapse time of the implosive shock wave is $\tau_{\text{coll}} = 1.13 \times 10^8$s. Since $\tau_{\text{cool}} \gg \tau_{\text{coll}}$ the shock is able to collapse completely and even reach a situation of bouncing back as a kind of explosive shock wave. At the time of collapse the radius of the cloud diminishes to a value of $37600\,\text{AU}$. When this stage is reached, the post-shock values for the pressure, density and temperature are found to be $0.01\,\text{Pa}$, $1500\,\text{cm}^{-3}$ and 1.81×10^{12}K respectively. Under this circumstances, the squared ratio of the post–shocked Jeans mass M_{J2} to the pre–shocked Jeans mass M_{J1} of the cloud reaches a value of 6.6×10^{34}. This means that the Jeans mass of the cloud grows on a very great proportion and so, a gravitational collapse can not occur at least for the adiabatic solution presented here.

In summary, we have prooved that a gravitational collapse is not possible under the model presented here. So, under these circumstances no star formation is induced by the passage of the radio jet through clouds embedded in the interstellar medium of the host galaxy. However, this model suggests another form of shock radiation that might be presented when clouds get embedded in the radio lobes of powerfull radio galaxies.

4

It is important to note that radiation and self–gravity of the cloud was not included on our calculations. We intend to do a full 3D simulation including these physical ingredients in the future.

Acknowledgements

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